Aug. 10, 1954 I. M. LEVITT ET AL 2,686,269

HIGH-VACUUM ELECTRONIC PHOTOTUBES

Filed April 20, 1948

Fig. 1

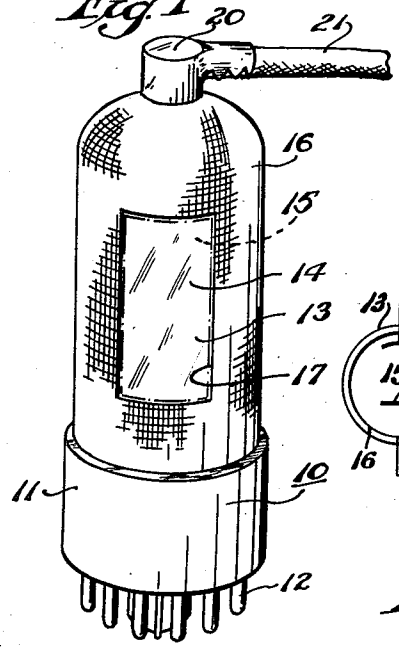


Fig. 7

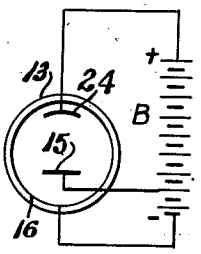


Fig. 2

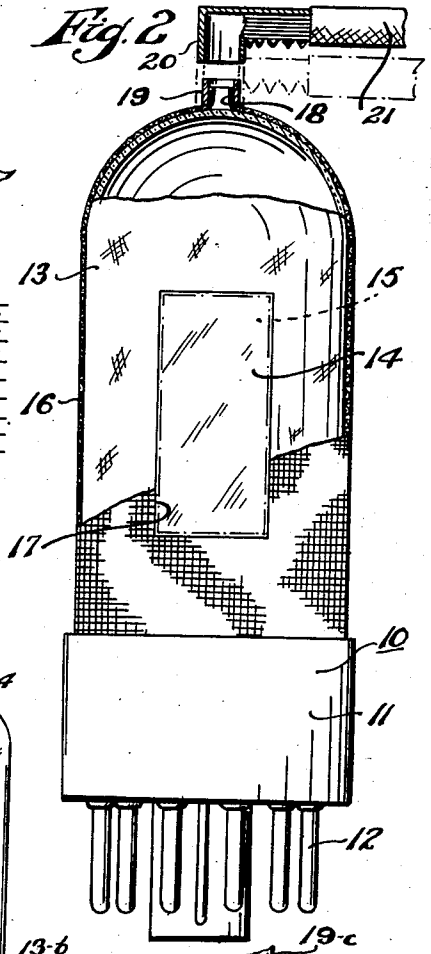


Fig. 5

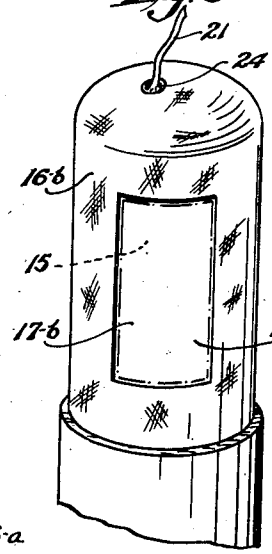


Fig. 4



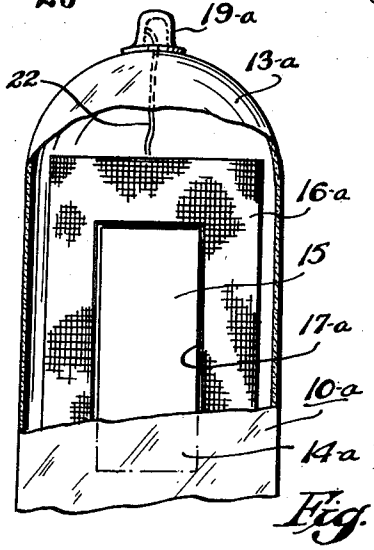


Fig. 3

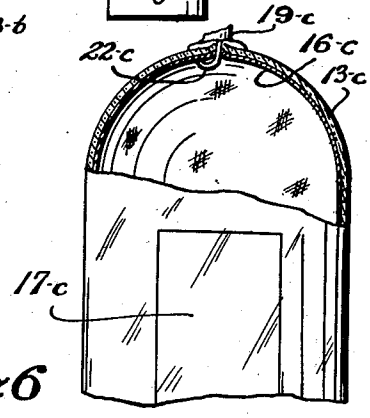


Fig. 6

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HIGH-VACUUM ELECTRONIC PHOTOTUBE

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5 Claims. (Cl. 250—211)

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The present invention relates to certain new and useful improvements in high-vacuum electron tubes of the phototube, and particularly the multiplier phototube, type and it relates more particularly to a new and improved construction for tubes of the aforesaid type whereby they are enabled to detect and measure light at much lower intensities than has heretofore been possible.

An object of the present invention is to provide a new and improved construction for high-vacuum electron tubes of the phototube, and particularly the multiplier phototube, type. Another object of the present invention is to provide a multiplier phototube having a high degree of efficiency and accuracy and capable of detecting and measuring low-intensity light with minimum error. Still another object of the present invention is to provide a new and improved construction for multiplier and other tubes whereby the error resulting from the effect of "dark current" is minimized.

Other objects and advantages of the present invention are apparent in the following detailed description, appended claims and accompanying drawings.

Electronic phototubes have been used for many years as a means for detecting a light-source and for measuring intensity of the light-source. The essential elements of all such phototubes are a light-sensitive cathode capable of electronic emission under the action of light and an anode to which the electrons so emitted are attracted.

In phototubes of the multiplier-type, additional elements known as dynodes are included for the purpose of amplifying (by secondary emission) the signal of the cathode before transmitting it to the anode, so as to make the tube more sensitive to relatively low intensity light.

These dynodes are maintained at successively higher voltages so that the cathode signal is picked up by the first dynode, amplified and transmitted in turn to the successive dynodes until it reaches the anode which is at a higher voltage than the last dynode.

Among the commercially available multiplier phototubes are those produced by Radio Corporation of America and identified as types 931–A and IP21. Both of these are nine-dynode multiplier phototubes of generally the same construction. However, the sensitivity characteristics vary greatly as between individual tubes so that they are graded into various types including those mentioned above; the 931–A being the least sensitive and the IP21 being the most sensitive,

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the latter costing approximately five times as much as the former.

While conventional multiplier phototubes provide effective determination and measurement of light sources having relatively high intensity, they give poor results when the intensity of the light source drops to an extremely low value such as is the case in measuring the light emanating from distant stars. This is due to an inherent characteristic of this type of tube which is commonly referred to as the "dark current." This "dark current" is the result of thermionic emission or ion feed-back which is characteristic of all high vacuum tubes and which is independent of, and in addition to, the photo-emission resulting from the impingement of the light upon the cathode. This thermionic emission varies as a function of the operating temperature of the tube and necessarily introduces an error into the reading obtained from the phototube.

Where the light source is of relatively high intensity the photo-emission value is considerably greater than the thermionic emission value and, accordingly, the error due to "dark current" is not excessive and the readings can be corrected to give fairly accurate light-measurement.

Where, however, the photo-emission drops to a relatively low value (as is the case where very weak intensity light sources are being measured) the ratio of signal-to-noise (that is, photo-emission to thermionic emission) correspondingly drops and, in conventional phototubes reaches a value of unity or less-than-unity which makes the error so great as to render the readings meaningless.

This defect in conventional constructions has heretofore been recognized and, in an attempt to remedy the situation, it has been suggested that refrigeration of the phototube be employed to reduce its operating temperature (and correspondingly to reduce its "dark current").

Refrigeration of the phototube obviously represents a cumbersome, complicated and costly operation which has proven to be of only limited practical value.

According to the present invention, there has been developed, for the first time, a simple and inexpensive construction for phototubes which eliminates the short-comings of the prior-art and which provides accurate and dependable amplification of low-intensity light signals and which substantially reduces the error resulting from "dark current" and which permits the use of the relatively less costly phototubes in place

of the relatively more costly tubes which have heretofore been required in the measurement of low intensity light signals.

Generally speaking the present invention contemplates the use of an electrically conducting shield-like thermal-electron control-electrode disposed in enveloping relationship to the operating elements of the phototube, except for a light-transmitting window in alignment with the cathode, said shield-like thermal-electron control-electrode having a negative charge and having a voltage potential more negative than that of the cathode by about 1 to 200 volts and more preferably about 20 to 100 volts; this shield tending to minimize the "dark current" of the phototube in a manner to be more fully discussed hereinbelow.

For the purpose of illustrating the invention, there are shown in the accompanying drawings forms thereof which are at present preferred, although it is to be understood that the various instrumentalities of which the invention consists can be variously arranged and organized and that the invention is not limited to the precise arragements and organizations of the instrumentalities as herein shown and described.

Referring to the accompanying drawings in which like reference characters indicate like parts throughout:

Figure 1 represents a perspective view of one embodiment of the present invention.

Figure 2 represents an elevational view, on a somewhat enlarged scale, of the embodiment of Figure 1, parts being broken away better to reveal the construction thereof.

Figure 3 represents a fragmentary view, partly in elevation and partly in cross-section showing another embodiment of the present invention.

Figure 4 represents a schematic plan view showing the shield of Figure 3 as it would appear when mounted within the glass envelope of a nine-dynode multiplier phototube.

Figure 5 represents a perspective view generally like that of Figure 1 but showing still another embodiment of the present invention wherein the shield-like thermal-electron control-electrode is in the form of a coating of silver or the like applied directly to the outside of the tube.

Figure 6 represents a fragmentary view, partly in elevation and partly in cross-section showing a modification of the embodiment of Figure 5 wherein the coating is applied to the inner surface of the tube.

Figure 7 represents a diagrammatic view of the circuit for the tube of Figures 1 and 2.

Referring now to the embodiment of Figures 1 and 2, there is shown a phototube 10 of generally conventional construction including a base 11 having terminals 12 projecting downwardly therefrom and an evacuated glass tube or envelope 13 mounted upon the base in conventional manner. The outside of the glass tube 13 is painted or sprayed or otherwise rendered opaque execept for a generally rectangular transparent window 14.

Disposed within the evacuated envelope 13 is a conventional light-sensitive cathode 15, in alignment with and closely adjacent to the window 14; the window 14 being generally the same shape as the cathode 15 but being slightly larger in transverse and longitudinal dimension as indicated particularly in Figure 2.

An anode 24 (see Figure 7) of conventional construction is also disposed within the envelope 13. If the phototube 10 is of the multiplier type, the envelope is also provided with a number of dynodes (not shown) of conventional construction for the purpose of amplifying (by secondary emission) the magnitude of the photoemission of the cathode before feeding it to the anode in order to increase the sensitivity of the phototube. However, the tube 10 need not necessarily be a multiplier-type tube, in which case, no dynodes are present within the envelope 13.

Fitted closely about the outside of the glass envelope 13 is a shield-like thermal-electron control-electrode 16 of electrically-conducting material. In the embodiment shown in the drawings, the shield-like thermal-electron control-electrode 16 may take the form of a closely woven wire-mesh structure, although it is apparent that various modifications (for example thin metal foil or a sheet-metal sleeve) could be employed equally well.

The shield 16 has an opening or window 17 corresponding generally to the window 14 in the glass envelope 13; the two windows being in alignment so as to permit light to pass therethrough and to impinge upon the cathode 15.

An integrally formed upward projection 18 is provided at the top of the jacket 16 and a terminal post 19 in the form of a metal sleeve is securely soldered or otherwise appropriately fastened thereto.

A connector 20 of the grip-cap type, fastened to a wire lead 21, is adapted for quick attachable-and-detachable connection to the terminal post 19 in the manner illustrated in Figure 2; the lead 21 being connected to a convenient source of voltage potential (not shown) which will impart to the jacket 16 an appropriate negative voltage potential which, as mentioned hereinabove, should be somewhat greater than the cathode-voltage.

The lower edge of the jacket 16 may be cemented or otherwise secured to the base 11 (which is of non-conducting material) although this may be dispensed with.

The operation of the jacket 16 in minimizing "dark current" in the phototube 10 can be explained as follows:

As mentioned hereinabove, the impingement of light upon the cathode 15 (which may be constructed of, or coated with, potassium or caesium or strontium or other suitable light-sensitive material) causes it to emit electrons which may be designated as "photoelectrons." These photoelectrons travel directly to the anode in a simple phototube and in the case, of a multiplier phototube, travel to the first dynode where amplification, by secondary emission, takes place resulting in a larger flow of photoelectrons to the next higher-charged dynode, and so on, until, finally, a considerably amplified flow takes place from the last dynode to the anode, which has a potential more positive than that on the last dynode.

As also mentioned above, the electronic characteristics of phototubes (common to all vacuum tubes) are such that additional electrons, the so-called thermal electrons, are thrown off by the cathode (and also by the dynodes in the case of multiplier phototubes); these thermal electrons causing the "dark current" which varies as a function of the operating temperature of the tube and is independent of, and in addition to, the photo-emission resulting from the light impinging upon the cathode.

According to the present invention, it has been found that the use of the negatively charged

shield-like thermal-electron control-electrode 16, which, as mentioned above, is at a potential somewhat more negative than that of the cathode (approximately two to ten per cent higher and, preferably, about five per cent higher) effectively represses the thermal electrons (so as to reduce the undesirable "dark current") with no appreciable effect upon, or interference with, the photoelectrons.

The following may be an explanation for this phenomenon, although the present invention is not to be construed as depending thereupon or as being limited thereto.

The mean energy of electrons resulting from thermionic emission is substantially less than the mean energy of electrons resulting from photoemission. Thus, the mean energy E of thermal electrons (as calculated by the equation $E=2KT$, where K is Boltzmann's constant and T is absolute temperature) is about 0.05 electron-volt at 300° absolute. The mean energy of photoelectrons is considerably greater than this value; the electrons resulting from the impingement of green light, for example, upon the cathode having a value of about 1.0 electron-volt.

The use of the shield-like thermal-electron control-electrode 16 with its negative charge somewhat more negative than the charge on the cathode results in a negative field having a potential generally of the same order as, or slightly greater than, that of the thermal electrons, so that they are effectively repelled and localized at the cathode (and at the dynodes) at which they originate and are kept from passing on to the anode. However, this field has no appreciable restraining force on the higher energy photoelectrons so that the light-sensitivity of the phototube is unimpaired by the shield-like thermal-electron control-electrode. Thus, the "dark current" of the phototube would be effectively minimized without appreciably reducing the photoemission value.

It is obvious, therefore, that the use of the charged shield-like thermal-electron control-electrode 16 reduces the signal-to-noise ratio and permits the use of the phototube in measuring the intensity of much weaker light sources than has heretofore been possible.

The probable error in calculations of light-intensity by the photo-electric method is determined by the ratio of the average energy value of dark-emission to the average energy value of photoemission. By keeping the former value at a minimum, the novel construction of the present invention reduces the probable error to as little as one-fourth of its normal value so that correspondingly weaker light-intensities can be measured with reasonable accuracy.

In addition, the use of the charged shield-like thermal-electron control-electrode 16 permits the use of much less expensive phototubes than would otherwise be required.

Thus, as mentioned hereinabove, multiplier phototubes of generally identical construction can vary considerably in their sensitivity to light and are selectively graded and correspondingly priced; the more sensitive phototubes being many times greater in cost than the less sensitive.

It has been found that, by use of the charged shield-like thermal-electron control-electrode 16 of the present invention, a 931–A phototube which may cost about $10.00) will give as good results as can be obtained with an IP21 tube (which may cost about $50.00) without the shield-like thermal-electron control-electrode.

The signal reaching the anode of the phototube can be detected either by measuring the current-flow (in micro-amperes, using a galvanometer or similar instrument) or by measuring the rate of pulsation (which is an inherent characteristic of multiplier phototubes resulting from the charging and discharging of the anode by bursts of electrons) as more fully described in our article entitled "Counting light by counting pulses" in the October 1947 issue of The Pennsylvania Gazette (volume 46, No. 2, page 12 et seq.).

In Figures 3 and 4 there is shown a modified embodiment of the present invention wherein the shield-like thermal-electron control-electrode 16–*a* is disposed inside the glass envelope 13–*a* more closely adjacent the operating elements of a 9-dynode multiplier phototube 10–*a*. In this embodiment, the window 17–*a* of the shield 16–*a* is disposed intermediate the window 14–*a* of the glass envelope 13–*a* and the cathode 15, and the shield 16–*a* is provided with a wire 22 passing through the top of the glass tube 13–*a* connecting with a terminal-post 19–*a* (to which the connector 20 can be attached in the manner described hereinabove in connection with the embodiment of Figure 2).

The operation of the embodiment of Figures 3 and 4 is generally the same as that described hereinabove in connection with the embodiment of Figures 1 and 2.

However, since, as shown in the diagrammatic view of Figure 4, the shield 16–*a* is much closer to the cathode 15 and the dynodes 23 than is the case with the external shield 16 of Figures 1 and 2, it is more effective in restraining the emission of thermal electrons and thereby minimizing "dark current." Indeed, under some circumstances, it may be desirable to reduce the extent of the excess charge upon the shield, as compared to that employed in connection with the embodiment of Figures 1 and 2.

By way of illustration, it may, under certain circumstances, be desirable to maintain the charge on the shield 16–*a* at a value only two or three percent greater than the charge on the cathode (as compared to the five percent figure preferred in connection with the embodiment of Figures 1 and 2).

In Figure 5 there is shown still another embodiment of the present invention wherein the shield-like thermal-electron control-electrode is formed as a deposit or coating 16–*b* of silver or other appropriate electrically-conducting material, which is chemically or electrically deposited or otherwise appropriately applied directly to the outside surface of the glass envelope 13–*b*, with an appropriate clear space or window 17–*b* provided in line with the cathode 15. In this embodiment, the bare end of the wire lead 21 can be soldered or otherwise connected directly to the coating 16–*b* as at 24.

It is apparent that, by applying coating 16–*b* to the entire outer surface of the glass envelope 13–*b*, it serves the dual purpose of an electrically charged shield and an opaque coating, thereby eliminating the separate opaque coating of the embodiment of Figure 1.

The operation of the embodiment of Figure 5 is the same as that described hereinabove in connection with the embodiment of Figures 1 and 2.

In Figure 6, there is shown a further embodiment of the present invention wherein the shield-like thermal-electron control-electrode is formed as a deposit or coating 16–*c* which may

be collodial carbon or other appropriate electrically-conducting material which is not photo-emissive. Silver should not be used as an inner-coating since it is photo-emissive to some extent and may interfere with the proper functioning of the phototube. The deposit or coating 16–c may be chemically or electrically deposited or otherwise appropriately applied directly to the inside surface of the glass envelope 13–c, with an appropriate clear space or window 17–c provided in line with the cathode 15. In this embodiment, a wire lead 22–c extends from the inner coating 16–c through the wall of the glass envelope 13–c and connects with an upper terminal post 19–c which is adapted to receive the connector 20 as described hereinabove.

In this embodiment, the inner deposit 16–c also serves the dual purpose of an electrical shield and an opaque coating, as in the embodiment of Figure 5.

The operation of this embodiment is generally the same as that of the embodiment of Figure 1, as described hereinabove.

By the use of the term "phototube" in the claims, we mean to comprehend both a multiplier cell as well as a non-multiplier type vacuum photo cell.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof, and it is therefore desired that the present embodiments be considered in all respects as illustrative and not restrictive, reference being had to the appended claims rather than to the foregoing description to indicate the scope of the invention.

Having thus described our invention, we claim as new and desire to protect by Letters Patent:

1. A high-vacuum phototube including a light-sensitive cathode, an anode, dynodes and a thermal-electron control-electrode disposed in enveloping relationship to said cathode and anode for forming an electrostatic field enveloping said cathode and anode and dynodes, said thermal-electron control-electrode being electrically insulated from all other metallic parts of the phototube which may be electrically contacted by the tube-receiver in which the tube may be operatively received and being arranged to retain a negative voltage impressed thereon.

2. A high-vacuum phototube including a light-sensitive cathode, an anode, dynodes, a negatively chargeable thermal-electron control-electrode disposed in an enveloping relationship to said cathode and anode and dynodes for forming an enveloping electrostatic field, said control-electrode being electrically insulated from all other metallic parts of said phototube and means for impressing a negative potential on said control-electrode, said negative potential being a potential more negative than that of the cathode thereby to cause the aforesaid enveloping electrostatic field to turn back the thermal-electrons emanating from said cathode and thereby to influence the operation of said phototube by said electrostatic field.

3. A high-vacuum phototube including a light-sensitive cathode, an anode and a thermal-electron control-electrode disposed in enveloping relationship to said cathode and anode for forming an electrostatic field enveloping said cathode and anode, said thermal-electron control-electrode being electrically insulated from all other metallic parts of the phototube which may be electrically contacted by the tube-receiver in which the tube may be operatively received and connected to a potential which is negative in respect to the cathode, and an optically-clear light-path window in said enveloping thermal-electron control-electrode in operative juxtaposition to the aforesaid cathode.

4. A high-vacuum phototube including a light-sensitive cathode, an anode and a thermal-electron control-electrode disposed in enveloping relationship to said cathode and anode for forming an electrostatic field enveloping said cathode and anode, said thermal-electron control-electrode being electrically insulated from all other metallic parts of the phototube which may be electrically contacted by the tube-receiver in which the tube may be operatively received and connected to a potential which is more negative than that of the cathode by about 1 to 200 volts, and an optically-clear light-path window in said enveloping thermal-electron control-electrode in operative juxtaposition to the aforesaid cathode.

5. A high-vacuum phototube including a light-sensitive cathode, an anode and a thermal-electron control-electrode disposed in enveloping relationship to said cathode and anode for forming an electrostatic field enveloping said cathode and anode, said thermal-electron control-electrode being electrically insulated from all other metallic parts of the phototube which may be electrically contacted by the tube-receiver in which the tube may be operatively received and connected to a potential more negative than that of the cathode and of a magnitude approximately 5% that of the total potential across the phototube, and an optically-clear light-path window in said enveloping thermal-electron control-electrode in operative juxtaposition to the aforesaid cathode.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,013,095	Friend	Sept. 3, 1935
2,161,859	Geffcken et al.	June 13, 1939
2,232,220	Ferndel	Feb. 18, 1941
2,251,653	Berg	Aug. 5, 1941
2,339,053	Coleman	Jan. 11, 1944
2,438,587	Taylor	Mar. 30, 1948

FOREIGN PATENTS

Number	Country	Date
323,041	Great Britain	1930